DOCUMENT RESUME

ED 459 598 EF 006 046

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TITLE	Lighting for Schools.
INSTITUTION	National Clearinghouse for Educational Facilities, Washington, DC.
SPONS AGENCY	Educational Resources Information Center (ED), Washington, DC.
PUB DATE	2001-12-00
NOTE	7p.; With contributions by Barbara Erwine.
AVAILABLE FROM	For full text: http://www.edfacilities.org/pubs.
PUB TYPE	Reports - Descriptive (141)
EDRS PRICE	MF01/PC01 Plus Postage.
DESCRIPTORS	Educational Facilities Improvement; Elementary Secondary Education; *Energy Conservation; Guidelines; *Lighting; Public Schools
IDENTIFIERS	*Cost Containment

ABSTRACT

This publication highlights some of the benefits of proper daylighting design in educational facilities, discusses energy efficient electric lighting choices schools can make that are long lasting and require little maintenance, and offers six steps for designing lighting systems that use half the energy of earlier conventional designs. Several light sources and systems are listed along with their mean lumens per watt, luminary usage, and types of school spaces where they would be used. (GR)

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Lighting for Schools

National Clearinghouse for Educational Facilities

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December 2001

Lighting is and always has been an important factor in designing and operating schools. Until the 1950s, natural light predominated as a means of illuminating most school spaces. Classroom design was based in large part on time-honored relationships between window sizes and room dimensions. As electric power costs declined and designers began to take advantage of the increased flexibility provided by electric lighting, daylighting took a secondary role. Now, highly energy efficient windows and skylights and a renewed recognition of the positive psychological and physiological effects of daylighting (Heschong Mahone Group) allow a healthy and economical mix of natural and electric illumination in new and renovated schools.

Responsible Daylighting

Simply adding windows or skylights to a classroom is not necessarily responsible daylighting. Poorly designed daylighting, as with poorly designed electric lighting, can create visual discomfort and disabling glare. Incorrectly placed daylighting can introduce undesirable solar heat gain, causing discomfort and increasing ventilation and air conditioning loads and energy use.

Good daylighting design requires understanding a building's local climate and use patterns and the location, placement, and shading of windows and skylights relative to their solar orientation. A good daylighting system provides:

- balanced, diffuse, glare-free daylight from two or more directions;
- sufficient light levels for the tasks in the space;
- operable shading devices to reduce light intensity for audio-visual programs and computer work;
- windows for interest, relaxation, and communication with the outdoors; and,
- exterior shading devices as needed to minimize solar heat gains during the cooling season.

The concept of *cool daylighting* is a systematic approach to daylighting design that ensures that the daylight is controlled through a combination of glazing systems (such as low-e), shading systems, and architectural design. The result is a building that uses significantly less energy than an ordinary school by simultaneously reducing electric lighting and cooling loads. However, to be effective, daylighting must be supplemented by automatically controlled electric lighting that dims in response to daylight levels.

There is a side benefit to daylighting: by turning off the electric lights when they are not needed, the life of the electric lighting system is extended and maintenance costs are reduced. A simple automatic photo-control system can switch off one, two, or three fluorescent lamps per light fixture, depending upon the amount of daylight present. By reducing the use of the electric lights by 50 percent, their life span will be doubled and associated maintenance costs cut in half.

Daylighting can be effective and energy efficient for almost all school spaces, including classrooms, cafeterias, offices, shops, gyms, pools, corridors, locker rooms, and study halls. Some daylighting approaches, especially top lighting (skylights), can be added to existing buildings. For instance, many gyms could easily employ simple, reliable commercial skylights that would allow lights to be turned off during much or all of the day. This saves energy and reduces the cost of maintaining the electric lighting system, a significant expense.

Although daylighting design for classrooms can be as simple as installing good windows, the best designs often employ clerestories and other more complex lighting devices such as light shelves. Remember, windows that provide a view can also introduce glare. Windows also introduce side light, which usually is not as good as top light for illuminating tasks.

In summary, daylighting is beneficial to student learning in addition to simply being pleasant. Employed correctly, daylighting can dramatically cut electric lighting, energy, and maintenance costs, even in cloudy or northern latitudes. The resultant energy savings can, in the long term, offset the increased costs of adding daylighting while increasing comfort and student performance.

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Electric Lighting Choices

Even if the school is well daylighted, an electric lighting system is needed for inclement days, early and late winter hours, and evening classes. The challenge is to provide a lighting system that is energy efficient, has a long life, and requires minimal maintenance.

Lamp technology. For the greatest energy efficiency and best color rendering, school lighting should employ either fluorescent T-8 or T-5 linear lamp technology with electronic ballasts. The latest T-8 lamps, called *second generation*, produce more than 10 percent more light per watt than the original T-8 lamps and 50 percent more light per watt than the old T-12 lamps (still the most commonly used lamps in older schools). The second-generation T-8 lamps are currently about 30 percent more expensive than ordinary T-8 lamps, but their superior color and light output are worth the cost and they last about 20 percent longer. In a typical classroom, the added cost of purchasing second-generation lamps (as compared to T-8 generic lamps) is about $5 per year. However, if the additional light from the lamps is utilized through good design practice, the classroom will use about 200 fewer watts and will save about $50 per year in energy costs. T-8 lamps can be easily retrofitted into existing lighting systems.

T-5 linear lighting systems are best suited to new schools or schools undergoing major remodeling. They are most effective when used for suspended uplighting, direct-indirect pendant lighting, cove lighting, undercabinet lighting, or in specialized applications. Because the T-5 lamp and ballast system is more expensive than the T-8 system, the two systems should be compared to determine which best meets a school's needs. The T-5 HO (high output) lighting system is rapidly gaining prominence as the preferred lighting system for gymnasiums, pools, and other spaces with high ceilings.

Compact fluorescent lamps should replace incandescent lamps in downlights, wall bracket lights, and utility lights. Because of improvements in low temperature performance, compact fluorescent lamps also may be used for some exterior lighting applications such as canopy downlights, utility wallpacks and some types of security lighting.

High intensity discharge (HID) lamps should be used primarily outdoors (in parking lots, athletic fields, and high-wattage exterior lights) and for a few interior applications. Metal halide lamps are strongly recommended (as opposed to high-pressure sodium) for their good color rendering and white light, which provides better night vision. Until recently, HID lamps were used in gyms, pools, and other spaces with high ceilings. With the advent of T-5 HO and multiple compact fluorescent lamps, however, indoor applications for HID lamps should be chosen carefully and only after weighing a fluorescent alternative. The reason is simple: fluorescent systems generate more light per watt and provide superior color. The exception is high color-rendering ceramic metal halide lamps. These new lamps are not nearly as energy efficient as fluorescent lamps, but they are the most efficient source for display lighting and a few other specialty applications where color rendering is important.

There are very few applications for traditional tungsten sources of any kind. The short lamp life and low energy efficiency of tungsten lamps make them a poor choice. They should only be used in theaters, art galleries, and in spaces where dimming is important, such as multipurpose rooms. The latest halogen IR (infrared) lamps should be specified, for they produce light about 33 percent more efficiently than ordinary incandescent lamps.

On the horizon, new light sources such as light-emitting diodes (LEDs) and induction lamps may ultimately change the way we approach lighting. The only current practical application of LED technology, however, is for exit and directional signs, and induction lamps are cost effective only when used in places that are difficult and costly to maintain (induction lamp life is generally five times longer than the best fluorescent lamps). A few other sources might be considered for special applications, such as cold cathode lighting, neon, and fiber optics, but, if used extensively, these sources will generally prove to be costly and comparatively inefficient.

The table on page 3 is a guide for choosing electric lighting systems for school applications. Note that *mean lumens per watt* is the measure of the energy efficiency of the lamp system, much the way miles per gallon measures the energy efficiency of an automobile. And a *luminaire* is the proper term for a lighting fixture.

Lighting fixtures (luminaires). Much of the lighting equipment used in schools is, and should be, commercial grade, similar to the equipment used in offices, stores, and other kinds of commercial buildings. When choosing lighting systems and fixtures, think about efficiency, glare control, durability, cost, and maintainability, for which there are many cost-effective choices. New lighting trends to consider (see page 4):

Lighting Sources for School Uses

Light Source/System	Mean Lumens per Watt	Luminaires	Types of Spaces in a School
Fluorescent T-5 linear with programmed start electronic ballasts (24-, 36-, 48-, and 60-inch lengths)	91	Specialty lighting, such as under-cabinet, suspended indirect, wallwashing	Classrooms, offices, multipurpose rooms, libraries
Fluorescent T-8 second-generation linear with electronic instant start ballasts or programmed start ballasts (24-, 36-, 48-, and 60-inch lengths)	92	General lighting in troffers, suspended lighting systems, wraparounds, strips	Classrooms, offices, multipurpose rooms, lockers, toilets, stairs, libraries, utility areas, hallways, corridors, labs, music rooms, shops, studios
Fluorescent T-5 HO linear with programmed start electronic ballasts (24-, 36-, 48-, and 60-inch lengths)	81	Specialty lighting applications where high lumen output is needed	Gyms, pools, libraries, offices, multipurpose rooms
Compact fluorescent triple tube lamps (18, 26, 32, and 42 watts) with electronic ballasts	50–72	Downlights, sconces, wallwashers, utility lights, wall brackets, table and task lamps	Lobbies, offices, multipurpose rooms, toilets, halls and corridors, utility spaces, exterior canopies, walls, bollards, utility applications
Pulse start metal halide lamps (250 watts or higher)	55–78	Industrial style downlights, parking lot lights, roadway lights, large wallwashers, specialized uplights, floodlights, sports lights	High-ceiling interior spaces (some gyms, pools), parking lots, sports fields, other pole-mounted exterior lighting
Pulse start ceramic metal halide lamps (150 watts or lower), with electronic ballasts	35–65	Track and recessed display lighting	Feature displays
Halogen IR lamps (60 to 100 watt PAR-38, 50 watt PAR-30) or low voltage halogen IR lamps (37 watt MR16)	20–30	Track and recessed display lighting, surface and recessed downlighting	Feature displays and house lighting for theaters, performance spaces, and multipurpose rooms

- **Suspended indirect luminaires** are recommended in classrooms. Suspended indirect luminaires with relatively low-cost sheet metal bodies have become reasonably competitive with recessed troffer lighting. Indirect lighting provides a superior quality of light by illuminating the ceiling, which redirects light downward uniformly and without glare. However, to use these lighting systems, ceiling heights should be at least 9 feet 6 inches, and walls and ceilings should be a light color.
- **Direct-indirect luminaires,** which are more efficient than indirect luminaires alone, work well in classrooms. They are slightly more expensive to install, but high performance direct-indirect lighting expends about 20 percent less energy for the same light levels as indirect lighting alone. A ceiling of at least 9 feet is needed, and walls and ceilings should be a light color.
- **T-5 HO systems with specially designed reflectors** are the most efficient and economical systems for use in gyms and other spaces having high ceilings. These systems permit multiple-level switching and other control options that do not work with traditional HID lighting systems. Multiple compact fluorescent lamp luminaires and metal halide industrial luminaires also may be used, depending on ceiling heights and other factors.
- **Fluorescent and compact fluorescent vandal-resistant luminaires** are available in architectural styles that look pleasing, even when the school is built to withstand rough service.
- **Several other efficient fixtures** are available, such as the recessed indirect troffer that works well for corridors and other spaces.

An Energy-Efficient Lighting Plan

By following the six steps below, it is possible to design lighting systems that use half the energy conventional designs used just a few years ago:

1. Use daylighting strategies throughout the school. Design the electric lighting so that lights can be adjusted in response to changes in daylight levels.

2. Select the best light source suitable for the application. Considering the excellent color quality available from modern fluorescent and compact fluorescent lamps, there is rarely a need to compromise. In a few cases, however, a good design might use a small amount of tungsten lighting or HID lamps. Carefully weigh all options before choosing.

3. Use the most efficient luminaires. For instance, modern direct-indirect luminaires are 85 to 90 percent efficient, as compared to the 60 to 70 percent efficiency of older styles. Many of today's luminaires are open bottomed, which minimizes dirt accumulation and assures good lighting performance even when maintenance is reduced.

4. Use luminaires that produce a good coefficient of utilization (CU). The CU takes into account the way a luminaire works within a particular space. This is especially important with indirect lighting systems, which have an excellent CU in a room with a flat ceiling 10 feet above the floor but have a reduced CU at higher ceiling heights.

5. Design using the latest recommendations of the Illuminating Engineering Society of North America (IESNA). The IESNA Lighting Handbook, 9th Edition, contains new recommendations for lighting levels (footcandles or lux). These levels and their applications can result in lower energy use when properly applied. See also IESNA's *Recommended Practice for Lighting for Educational Facilities* (IESNA).

6. Use modern lighting controls throughout the school. With electronic dimming ballasts, fluorescent dimming is quiet, flicker-free, and energy efficient. Automatic fluorescent dimming can be employed in every room with adequate daylighting, although this option is more expensive. Other types of modern lighting controls, including motion sensors and energy management systems, should be used to reduce operating time. Remember, the amount of money spent on energy is the power (kilowatts) of the system multiplied by the time it is operating (hours) and the price of electricity. Modern lighting controls save money by reducing the time that lights are used unnecessarily.

A high performance school should have a maximum lighting power usage for interior lighting of less than 1.2 watts per square foot. When combined with effective lighting controls, the total energy use of a high performance school is much lower than in ordinary schools. And when daylighting is used properly, schools can operate with very little lighting power under most peak conditions.

Frequently Asked Questions

Q: *I have heard that full spectrum lighting is good for use in schools. Is this true?*

A: Thirty years ago, the most common fluorescent lamps were cool white, which is a color of white light having a distinct bluish tint. People hated them. The idea of full spectrum lighting began in the 1970s as a sales tactic to promote particular brands of fluorescent lamps. Those specific lamps generate a bluish white light similar to natural daylight. Although the color of the lamp was significantly better than cool white, the manufacturers made claims about the lamps' health benefits. Many schools installed them as a result. The Food and Drug Administration ruled in 1985 that these full spectrum lamps provided no health benefits.

Modern T-8 versions of these lamps are available and provide a bluish light of high color quality. Consider using these 5000 K color-rated lamps for art studios because the color balance is better tuned for fine color discrimination. For most school lighting, however, lamps with a color rating of 3500 K or 4100 K tend to be preferred for economy and ease of obtaining replacements.

Q: *We live in the northern portion of the United States where natural light can be limited during the winter months. Should special lighting for treating seasonal affective disorder (SAD) be installed in our schools?*

A: SAD is a medical condition that requires a professionally managed program of lighting and medication. Contrary to popular belief, ordinary office and school lighting systems cannot be used to counter the effects of SAD. Proper treatment involves special lighting systems, and the lighting must be introduced in a clinical manner. However, the use of daylighting provides natural changes in illumination levels that are thought to be psychologically beneficial.

Q: *The security lights at our neighborhood school are on motion sensors and are not activated unless someone is near the school. Is this safe?*

A: The concept of the black-out school is based on the assumption that vandals will not be attracted to a blacked out building, especially when sensors activate lights to announce their presence. As long as the motion sensors are properly designed and avoid detecting small animals, this type of lighting approach is really quite clever. It saves energy, helps reduce light pollution, and permits the use of low-cost halogen floodlights instead of the more expensive HID or fluorescent lighting systems. It is not suitable, however, for a school's parking lot or other exterior lighting if the school has many evening events.

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Additional Information

See the NCEF resource lists *Daylighting* and *Lighting* online at *http://www.edfacilities.org/rl*

Acknowledgments

The author especially thanks Barbara Erwine for her significant additions to the text on daylighting.

Reviewers

James Ansley, Charles Eley, Barbara Erwine, Lisa L. Heschong, Randy Karels, Henry Sanoff, Thomas M. Tolen, and Terry Whitney.

Sponsorship

This publication was produced by the National Clearinghouse for Educational Facilities (NCEF), an affiliate clearinghouse of the Educational Resources Information Center (ERIC) of the U.S. Department of Education.

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